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The American Association for the Advancement of Science:

Geometry and Physics: PROFESSOR OSWALD VEBLEN 129

Pasteur—the Man: PROFESSOR GRAHAM LUSK 139

Scientific Events:

The Pan-Pacific Scientific Congress; International Conference of Phytopathology and Economic Entomology; Appalachian Field Trip; Report of the Director of the New York Botanical Garden 141

Scientific Notes and News 144

University and Educational Notes 147

Discussion and Correspondence:

Balancing Chemical Equations: DR. JAMES H. RANSOM. *A "Spindling-tuber" Disease of Irish Potatoes:* EUGENE S. SCHULTZ, DONALD FOLSOM. *Nicotine Sulphate, an Effective Vermicide for Sheep:* GEORGE H. LAMSON, JR. *Swarming Insects simulating Smoke:* PROFESSOR CARL HARTMAN 147

Quotations:

A Super-university 150

Problems in the Determination of Physical Properties 151

Special Articles:

Glue Bubbles: PROFESSOR CARL BARUS 151

The American Association for the Advancement of Science:

Botanical Sciences 153

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GEOMETRY AND PHYSICS[1]

TWENTY years ago the abstract point of view in geometry was becoming a familiar one to mathematicians. The essential element in the movement of thought at that time seemed to be the freeing of geometry from all reference to physical reality. Geometry as studied by mathematicians must be a set of propositions arranged in a sequence of logical deduction, proceeding from a set of unproved propositions (the axioms, or postulates) which are stated in terms of undefined elements. If the undefined elements are points and lines, for instance, the mathematician does not inquire what is a point or line. All he cares to know about them is stated explicitly in the axioms.

This point of view made it possible for the first time in history to see geometry as a clear-cut whole. It was definitely separated from philosophy on the one side and from other branches of physics and mathematics on the other. The result was a great gain for clearness of thought in all these fields, a gain which has not been accompanied by any loss of mutual contact or support.

During the following years mathematicians have continued to develop the postulational or logistic method, so that by now it has demonstrated its value as a practical scheme of arrangement and exposition in the most diverse branches of mathematics. While doing this it has, of course, lost in freshness what it has gained in respectability. But during the same period a series of brilliant discoveries in physics has been making the abstract point of view a vital issue in that science also.

If we examine the classical branches of physics we shall find that the main elements of the abstract point of view have been im-

[1] Address as retiring vice-president and chairman of Section A—Mathematics, American Association for the Advancement of Science, Boston, December, 1922.

plicit in them for a long time. In fact, if we state with sufficient clearness in physical terms what we mean by undefined elements, unproved propositions, and so on, we are apt to find that a physicist classifies these ideas as truisms of little importance. I am inclined to think that he is justified in this attitude, so far as practical results are concerned, during the earlier and cruder stages of physical theory. But experience is showing that when the results of a more refined experimental technique force a reconsideration of fundamental assumptions, the technique of the study of these assumptions must undergo a corresponding refinement. Let us therefore take the risk of banality and glance at some of the branches of physics from the point of view of an axiomatist.

Lest any one should expect any closely reasoned body of doctrine to result from such a survey—and thereby be sadly disappointed—let me remind any non-mathematicians who may be present that when a mathematician lays down the elaborate tools by which he achieves precision in his own domain, he is unprepared and awkward in handling the ordinary tools of language. This is why mathematicians always disappoint the expectation that they will be precise and reasonable and clear-cut in their statements about everyday affairs, and why they are, in fact, more fallible than ordinary mortals. Therefore, please be satisfied in this case with some rather disconnected remarks.

We shall begin with elementary geometry, the oldest branch of physics. Having the mathematical, or abstract, science of geometry before us in its present highly developed form, we wish to apply it to the world of experiment. It consists of a sequence of statements arranged in a certain logical order but void of all physical meaning. In order to apply them to nature we identify the undefined terms (points, lines, etc.) as names of recognizable objects. The unproved propositions (axioms) are then given a meaning, and we can ask whether they are true statements. If they are true, then we expect that the theorems which are their logical consequences are also true and that the abstract geometry will take its place as a useful branch of physics.

This, I think, is a fair statement of the accepted point of view. But it is full of serious difficulties. The most obvious one is that it is impossible to identify anything in nature as a point or a line or a plane except by means of more or less gross approximations. The statement that a point has neither length, breadth nor thickness is a useful description in many of the applications of abstract geometry, but it is never strictly true of a physical point. The identification of any physical object as a point (or a hexagon or a sphere) takes place only with a certain margin of error. But if this error is imperceptible in verifying the postulates themselves, there may well be an accumulation of errors when the postulates have been used many times in the proof of a complicated theorem. Thus the postulates may appear true within the limits of error of a direct test, and yet some of the theorems may be perceptibly false. This makes it necessary to verify not merely the postulates, but also as many theorems as possible.

Here let me digress long enough to point out the bearing of this on the problems of teaching. The branch of physics which is called Elementary Geometry was long ago delivered into the hands of mathematicians for the purposes of instruction. But, while mathematicians are often quite competent in their knowledge of the abstract structure of the subject, they are rarely so in their grasp of its physical meaning. In recent years this defect has become glaringly apparent and the teachers of elementary geometry are beginning to cultivate the experimental technique of the subject. What I wish to say is that they should do this with a view not merely to making the concepts of geometry clear to their students, but also with a view to removing the legitimate doubts of its truth which students have a right to entertain.

The knowledge that the experimental verification of any theorem, however far removed from the axioms, is a real argument in favor of the validity of the whole science should strengthen the hands of those who want to make the teaching of geometry as concrete and physical as possible. Gauss and other experimenters who have taken pains to verify that the sum of the angles of a triangle is 180 degrees were not wasting their time; and neither is a teacher doing so who finds new

tests for this and other theorems of geometry.

At the same time it will not be forgotten that the physical reality of geometry cannot be put in evidence with full clarity unless there is an abstract theory also. The faults in the traditional teaching of geometry, about which we hear so much to-day, are in a large measure due to the opinion that geometry is a system of *a priori* truth of such a nature that our belief in it cannot be influenced by experiment. A science resting on such a supernatural basis was fittingly taught by the method of dogmatic indoctrination.

The existence of a margin of error in the process of identifying concretely the abstract terms of geometry means that we never verify a very large number of cases of a very large number of theorems in a single group of experiments. In one experiment, and with one interpretation of the terms, we verify the theorem of Pythagoras, but it is in another experiment, and with another interpretation of the terms, that we verify the theorem of Desargues. Thus we can know the physical truth of geometry only, as it were, in patches. The unity of the science is in its abstract formulation.

This situation is not an unusual one in physical science, for theories are by no means unknown in which the postulates and many of the theorems are quite beyond the reach of experiment. Such theories have to be tested by verifying some of their consequences. I suppose that it is a very exceptional theory which can be fully tested by a single series of experiments.

There is, however, an experimental difficulty which is especially characteristic of elementary geometry. This is the bewildering multiplicity of concrete interpretations for the same abstract term. A point, for the purposes of instruction, is usually a spot on a blackboard. If you are trying to steer a course at sea you may fix your attention on two points which are a lighthouse and a red spar respectively. In this case you are making use of the proposition that a straight line is uniquely determined by two of its points. The same proposition can be verified by driving the nails A, B, and C into a wooden board and observing that if a stretched string which touches A and B also touches C, then a stretched string which touches B and C can be made to touch A. The same experiment can be repeated by sighting from one nail to the others or by the use of a straight edge or by firing a bullet from a gun.

I could continue enumerating these illustrations indefinitely, but the point I am making is sufficiently evident. There is no unique way of defining a point or a line for the purpose of experiment. Indeed, the great usefulness of elementary geometry is very largely due to the fact that there is such an extraordinary multiplicity of things which can profitably be regarded as points and lines.

In this multiplicity of interpretation of its fundamental terms, elementary geometry is in sharp contrast with the more recent and recondite branches of physics. Thus, for example, while the term electron may have more than one physical meaning, it is by no means such a protean object as a point or a triangle. The old way of accounting for this difference was to say that the electron is a substantial object, whereas the point is only an abstraction. This way of dismissing the question will not satisfy us to-day, for we believe that the electron and the point are both abstractions. Moreover, the difference which we are seeking to explain is one of degree rather than of kind.

What we are calling elementary geometry is, of course, not a single logical unit. It comprises first of all a group of theorems of analysis situs. These culminate in the theorem that the points are in one-to-one correspondence with the totality of ordered sets of three numbers, (x, y, z); in other words, that an analytic geometry is possible. In this part of geometry, the multiplicity of possible physical interpretations of the terms is at its highest pitch. Following this we have projective geometry, the general theory of straightness; affine geometry, the theory of parallels; and, finally, the metric geometry. Each one of these groups of theorems is logically distinguished from its predecessor by the appearance of new relations which are brought in either by means of new axioms and undefined terms or by means of definitions which limit attention to a restricted class among the totality of possible geometrical objects. At each stage the freedom of physical interpretation is restricted

until, at the final stage, it is necessary to be able to specify the physical significance of a measuring stick and of a rectangular cartesian coordinate system.

Next after geometry, according to the classical way of looking at things, we can take up either kinematics or statics or the geometry of masses. Let us choose the first of these three alternatives.

For kinematics we must have a theory of time. This is very simple; the undefined terms are "instant" and "before" or "after," and we use as postulates one of the sets of postulates for the linear continuum. The main theorem is that there is a one-to-one continuous correspondence between the instants of time and the numbers of the real number system. This makes possible the subdivision of time into equal intervals, and the measurement of time. While the abstract theory is very simple at this stage, the physical applications involve all the technique of clocks and other time devices.

For kinematics we must also have the concept of substance, something which can move and which can have a duration in time. The postulates for substance will state its existence, as we say, in space and in time. They may be phrased somewhat as follows:

1. Given any substance and any instant of time, there exists a unique set of points called the *position* of the substance at the given instant of time.

A substance whose position at any time is a single point is called a *particle*.

2. The position of any particle at any time is a single point. This position is a continuous function of the time.

3. For every point P of the position of a substance S at any time there is a particle whose position is P. The position of S at any other time t' is the set of points which are the positions of these particles at the time t'. These particles are called the particles of the substance S.

4. No two particles of the same substance can have the same position at the same time.

5. Let (x_o, y_o, z_o) be the coordinates in a cartesian coordinate system of the position of any particle of a substance S at a time t_o and let (x, y, z) be the coordinates of the same particle at a time t, then there exist three analytic functions f_1, f_2, f_3 such that

$$\begin{aligned} x &= f_1 \ (x_o, y_o, z_o) \\ y &= f_2 \ (x_o, y_o, z_o) \\ z &= f_3 \ (x_o, y_o, z_o) \end{aligned}$$

for all the particles of S.

The first four of these postulates correspond to our most general intuitions about substance, and the fifth is intended as a basis for analytic operations. While I have studied out some of their consequences, I have not made anything like a full investigation and should not be surprised to find that they contain both omissions and redundancies. I give them here largely to emphasize the fact that very little work has yet been done in this direction.

Before we have the actual structure of the classical kinematics we must limit our attention not merely to the consequences of these axioms of time and substance, but also to a group of theorems determined by certain definitions. The most important of these is the definition of uniform motion of translation. A substance is in uniform motion of translation if with respect to a definite cartesian coordinate system and a definite time variable, we have for every particle of the substance

$$\frac{d^2x}{dt^2} = \frac{d^2y}{dt^2} = \frac{d^2z}{dt^2} = 0.$$

This simple way of stating the definition can be replaced by the apparently more complicated statement:

If a substance S is at rest there is a cartesian coordinate system and a system of time measurement such that the coordinates of each particle of S satisfy the conditions

$$\begin{aligned} x &= \text{constant} \\ y &= \text{constant} \\ z &= \text{constant} \\ t &= \text{arbitrary.} \end{aligned}$$

If a substance S' is in uniform motion of translation there is another coordinate system such that each particle of S' is denoted by

$$\begin{aligned} \bar{x} &= \text{constant} \\ \bar{y} &= \text{constant} \\ \bar{z} &= \text{constant} \\ \bar{t} &= \text{arbitrary.} \end{aligned}$$

and the relation between the two coordinate systems is given by equations

$$(1)\quad \begin{aligned} \bar{t} &= a\ \ t + b \\ \bar{x} &= a_{11}x + a_{12}y + a_{13}z + b_1 t + c_1 \\ \bar{y} &= a_{21}x + a_{22}y + a_{23}z + b_2 t + c_2 \\ \bar{z} &= a_{31}x + a_{32}y + a_{33}z + b_2 t + c_3 \end{aligned}$$

in which the coefficients are constants such that

$$d\bar{x}^2 + d\bar{y}^2 + d\bar{z}^2 = dx^2 + dy^2 + dz^2.$$

Before the physical applications can be made in detail, corresponding definitions must be made of uniform motion of rotation and of other special types of motion. But we need not go into this question here.

The physical interpretation of the abstract theory is much more definite and restricted at the present stage than it was at that of geometry. The table before us, the floor on which we stand, we ourselves, the whole earth, are all substances moving together through space with a high velocity. Any description of the whole or any part of this aggregation of substances is a concrete application of kinematics and gives rise to an experimental test of it.

We now see that the multiplicity of concrete interpretations of geometry was due in part (though not wholly) to the fact that geometry is used to describe an instantaneous cross section of the substantial universe. At this stage also we have to meet the difficulties due to the fact that the motion of any substance can only be detected physically as the motion of the one substance relative to the other substances.

The abstract theory which we have described provides for absolute motion, *i. e.*, a substance is in motion if the set of points which we call its position is not the same at all instants of time. But it is also true that the theorems of the universe of substance will be unchanged in meaning if we replace the abstract time and space which underlie the theory of substance by a new time and space related to the old ones by formulas of the same form as (1). It is for this reason that an absolutely definite statement of what we mean physically by particular substances does not carry with it a unique determination of what we mean by particular instants of time or points of space.

The fact, somewhat obscurely understood, that it is possible to make these transformations of the space and time underlying kinematics without altering the kinematics itself has often been taken as an argument against the classical theory of space and time. I do not think it can be accepted as a valid objection, however. What it really does prove is that when the classical theories of space and time are combined in the theory of substance, the result is more complicated than a simple-minded person would expect.

This complication of the abstract theory shows itself on the physical side when we ask how we shall know what are the simultaneous positions of two distant substances. The discussions of the theory of relativity have shown that the most natural physical method of answering this question corresponds with sufficient accuracy to the classical kinematics when attention is limited to terrestrial objects of not too fine-grained a character. On an astronomical scale, however, the determination of simultaneity fits in much better with the type of kinematics known as the special theory of relativity.

This theory we can regard as proceeding from exactly the same axioms of space, time and substance as those we have proposed for the classical kinematics. But it makes use of a different definition of uniform motion: A substance S' is in uniform motion of translation if, and only if, there is a coordinate system such that each particle of S' is denoted by $\bar{x}$ = constant, $\bar{y}$ = constant, $\bar{z}$ = constant, $\bar{t}$ = arbitrary, and the relation between this coordinate system and the (x, y, z, t) system is given by any set of linear equations with constant coefficient such that

$$d\bar{x}^2 + d\bar{y}^2 + d\bar{z}^2 - c^2 d\bar{t}^2 = dx^2 + dy^2 + dz^2 - c^2 dt^2$$

where c is a constant.

The relation of the relativity kinematics to its underlying space and time is quite analogous to that of the classical kinematics to its underlying space and time. Analogous transformations of the underlying space and time (the Lorentz group) are possible without changing the kinematics. But in the relativity theory these transformations are put in evidence in connection with the simplest problems, whereas the classical kinematics can be treated in such a way as to mask them.

This is not the place to go further with an exposition either of the classical or of the relativity kinematics. I wish only to remark that either of them can be based on an underlying

theory of space and time as well as upon the concept of a four dimensional space-time. There is no essential difference of logical simplicity between the two types of kinematics. The important difference is that the relativity definition of simultaneity is more nearly in accordance with the physical means in actual use by astronomers for determining when two events are simultaneous than is the classical definition. Therefore in those cases where the scale of operations is large enough, or the scheme of measurement fine enough, the relativity kinematics will be used. In other cases the classical kinematics will be retained as a sufficiently accurate approximation to the other.

In comparing the theorems of kinematics with experience there is much less overlapping than in geometry. For a physical object has to be identified as a substance in the kinematic sense not merely once but for all values of the time. Nevertheless, a great multiplicity of interpretation still persists, which will be further reduced when we come into the domain of mechanics.

Before we arrive at a full-fledged mechanics we must introduce the concept of mass. This may be done in two ways according as we are developing a mechanics of discrete particles or a mechanics of continuous substances. In the first case we have merely to postulate a number associated with each particle and in the second case to lay down a somewhat more extensive set of postulates from which the concept of density may be derived. These postulates will serve for example as a basis for the differential equations of continuity.

Finally the postulates must be introduced which determine how we shall use the terms force and cause. I shall not now try to set forth my ideas as to how these postulates should be formulated, for I have already gone more into detail than is desirable in a talk of this kind in expounding the idea of substance. It is enough to remark that there is an open field here for a valuable postulational investigation.

Suppose now that we have before us the complete logical structure which is built on these postulates and consider a particular mechanical problem, as, for example, the problem of two bodies. For the sake of this problem we add to the general postulates of mechanics the postulate that the substance to be considered consists of two particles of given masses moving under a particular law of force. The differential equations now become perfectly definite and numerical results can be worked out.

In order to have a physical application we may let the two particles be the two components of a double star. In this case the astronomical data have a low percentage precision and the theory gets along within a wide margin of probable error. Again, we may let the two particles be the sun and Jupiter. In this case the precision of the astronomical data is high. The theory serves as a first approximation. But it is soon seen that the sun and Jupiter must be regarded as parts of a more complicated mechanical system—and so, in order to pursue the astronomical problem further, we pass on to another abstract theory. In general a whole series of more and more complicated abstract theories will be applied to the same astronomical problem. But the further we go in this direction the more precise becomes the physical significance of each term and the further we are from that multiple interpretation of terms which we noted in elementary geometry.

The same sort of remarks can be made about any other mechanical problem—for example, the problem to find the position of equilibrium of a door hanging freely in a wind of given velocity on hinges whose axes make a given angle with the vertical. It is necessary to supplement the general assumptions of mechanics by additional ones which specify the particular problem. And when we have done so, the application to nature is very definite.

This state of affairs is in part due to the fact that the postulates for mechanics do not form a categorical set, and can not form a categorical set until the substance and the forces are specified in a particular way. In the narrow sense of the words, mechanics is not a mathematical science, but is the group of theorems common to a collection of sciences. Each particular problem involves certain axioms in addition to those of mechanics in general.

It should perhaps be emphasized once more that nothing of this sort is true of elementary

geometry. Its axioms form a categorical set. The relations among the points of space are completely determinate, and are unaffected by any of the additional assumptions required for a problem of mechanics. A typical problem of geometry is to determine the truth or falsity of a given theorem. Problems of this sort arise in mechanics, but a typical problem of mechanics requires the construction of a new theory. This is why mechanics is so interesting and so difficult.

The abstract treatments of a great many branches of physics fall within the province of mechanics as it is here understood, but there are a number of others, such as the theory of heat and of electromagnetic phenomena, which are not thus included and which I can not touch on now. But in their classical forms they have all had an underlying "space in which"—described by the Euclidean geometry—and an underlying time continuum. Situated in this space and time there are particles of substance (matter, electricity) all moving about under the influence of forces. The more abstract concepts, such as energy and entropy, have been defined in terms of these more easily comprehended undefined terms. But it is inevitable that the tendency to regard these new concepts as more and more fundamental should lead to the replacement of the old undefined terms by new ones which seem more adequate even if they are more perplexing.

An early illustration of the tendency to formulate problems in terms far removed from the obvious ones is to be found in the general equations of dynamics. Here we find as the coordinates of a dynamical system any set of parameters $q^1, q^2, \ldots q^n$ adequate to define it. In a very general class of cases these parameters are regarded as coordinates of a point in a Riemann space whose linear element is determined by the expression for kinetic energy. The geodesics of this space give the paths of the representative point of a mechanical system in the absence of impressed forces and the Lagrange equations express the divergences from these paths brought about by the impressed forces.

In this general mechanics the Riemann space figures as a mathematical device, in which it is highly suggestive to regard the geodesics as analogues of the straight lines in Euclidean space. For one of the most fruitful ways of looking at a straight line physically is to regard it as the path of a particle which has been given an initial velocity and is far enough away from other objects to be but little influenced by them. The motion of a particle in a general case is the result of a balancing of the tendency to follow a straight line with uniform velocity against the forces causing divergences from this norm. With the use of generalized coordinates this situation is reproduced in a generalized form in a Riemann space.

It is an important step beyond this to use the Riemann geometry from the very beginning as Einstein does in his theory of gravitation. To describe the motion of a particle which is left to itself, this theory does not presuppose an underlying space and time whose properties are completely determined in advance. Instead, it assumes that any event in the history of the particle can be identified in terms of four coordinates, x^1, x^2, x^3, x^4, and the totality of these sets of coordinates is assumed to constitute a Riemann space in which there is a linear element,

$$(2) \qquad ds^2 = \sum_{i,j} g_{ij}\, dx^i\, dx^j$$

The relations of these geodesics among themselves are different in the neighborhood of material bodies from what they are in regions where there are no material bodies. In regions of the latter type these relations are approximately the same as those among the geodesics of the space-time manifold of the special relativity.

The relations among the geodesics are determined by the functions g_{ij}. Therefore, if we wish to describe two different distributions of matter we require two different Riemann spaces. We can not, as in the old theories, simply put a new filler in the old container space. The allowable choices of the functions g_{ij} are restricted by requiring them to satisfy a set of partial differential equations which is chosen, in the main, on the basis of its simplicity. In one special case, the one-body problem, it is possible to solve these differential equations and obtain a set of g's and a Riemann space which correspond to a single mass of matter.

Let the numerical constant be chosen so that this mass represents the sun. The planets are

particles in comparison with the sun. Therefore, the orbits should be determined by the geodesics of this Riemann space. This determines for each planet a one-parameter continuous family of values of the quantities x^1, x^2, x^3, x^4, which can be compared with values obtained by observation.

Contrast this with the treatment of the same problem by the Newtonian method. Here we have a central attracting mass in a Euclidean space and a system of ellipses as the particle paths. If we go to the space-time manifold we get a system of spirals which have the ellipses as projections. Thus, in this case as in the other, we have a four-dimensional manifold and in it a system of curves. Although the mathematical theories from which the two systems of curves were derived are radically different, yet with proper restrictions the one system of curves can be regarded as a good approximation to the other, and we can pass from the one to the other by means of a differential correction.

When it comes to the comparison of these two systems of curves with nature, we have to recognize that the astronomers work out what they assign as the coordinates of the heavenly bodies by elaborate and indirect observation and calculation. The parameters which they thus determine have to be compared in a somewhat arbitrary way with those which enter into the abstract theories. It was found that in the case of the planet Mercury this fit could not be made with complete exactness for the classical theory, but that when the differential correction was applied which corresponds to the transition to the new theory, the fit became as good as could be expected.

The differential equations of the geodesics can be written in the form

$$\frac{d^2x^i}{ds^2} + \sum_{\alpha,\beta} \Gamma^i_{\alpha\beta} \frac{dx^\alpha}{ds} \frac{dx^\beta}{ds} = 0. \tag{3}$$

Among the curves which satisfy these equations are not only the geodesics which we have been talking about, but also a family of curves for which $ds = 0$. These curves differ but little from those which represent the motion of light in the older theories. Let us therefore assume that the new curves represent the motion of light. If we do, the differential change from the old to the new curves gives the magnitude of the effect on light of a gravitational field. This effect was predicted by Einstein and the prediction was brilliantly fulfilled.

Both of these successes of the new theory have to do with properties of the differential equations (3) and only indirectly with the functions g_{ij} of (2). The functions $\Gamma^i_{\alpha\beta}$ which appear in (3) are expressed in terms of the g's in (2) but do not depend on the physical meaning of the g's. It is otherwise with the third important prediction of Einstein, that having to do with a shift of the spectral lines. This depends on an explicit physical interpretation of the g's. Its experimental verification is very complicated and whether the outcome will be favorable or unfavorable is doubtful. In the meantime it is interesting to notice that this prediction is logically separable from the other two.

The general situation which arises here is worthy of a great deal of study. A set of differential equations (3) in which the functions Γ are arbitrary, determines a system of curves having the property that any two points in a sufficiently small region are joined by one and only one of the curves. We are thus in the presence of a broad generalization of the Riemann geometry which it has been proposed, in a paper by Professor Eisenhart and myself, to call the geometry of paths. The intuitive idea suggested by this name is that we are dealing not with the empty void of analysis situs, but with a manifold in which we find our way around by means of the paths. It may also serve to remind us that we have a generalization of an inertial field, for the characteristic of a field of inertia is that through every point and in every direction, there is a path which may be taken by a free particle.

A system of paths is also that which takes the place of the ether which has played so varied a rôle in the physics of the last hundred years. It is the paths in the space-time manifold which are the bearers of the energies and stresses which lead to the properties of light and electromagnetism.

From the work of Weyl, who has made the most important contributions to the geometry of paths, it follows that there is not only an affine but also a projective geometry of paths.

The affine geometry consists of those theorems which deal with the concept of infinitesimal parallelism defined by means of the functions Γ. The projective geometry deals with those properties of the paths that are so general as to be independent of any particular definition of parallelism. That there is such a projective geometry follows from the fact that more than one set of functions Γ can be found to define the same set of paths.

Incidentally, it is an interesting comment on the progress of mathematics that the classification of theorems into projective, affine and metric is not here based on the group concept. For the group of a space of paths is in general the identity.

These remarks are, of course, very general and can have little meaning to one who has not given some consideration to the analytic details. But it is essential that they should be made in the sort of a survey I am attempting, because the geometry of paths can be regarded as a generalization both of the earliest part of elementary geometry and of some of the most refined of physical theories. The study of the projective, the affine and the metric geometry of paths ought to result in a comprehensive idea of what types of physical theory it is possible to construct along the lines which have been successful in the past.

The development of physical theories in the recent past has been characterized by a progressively greater and greater use of different types of non-Euclidean geometry. In all cases, however, the underlying analysis situs properties are the same. Whether we are dealing with three, four or n dimensions, we are dealing with a cell, *i. e.*, a portion of a manifold which can be mapped continuously on the interior of a sphere in a Euclidean space of the right number of dimensions.

The obvious question suggests itself, whether it will not be necessary in the future to reconsider this assumption also. The question whether space should be assumed to be continuous has indeed already been raised in a shadowy form by Riemann and others. But even if space be assumed continuous it does not follow that every point in it can be enclosed by a region like the interior of a sphere. Many examples to the contrary are known to students of analysis situs. One such example is a singular manifold defined by "polar coordinates" r, θ, φ, in which $(0, \theta, \varphi)$ represent a single point, the origin, no matter what θ and φ are and in which (r, θ, φ) represents the same point as $(r, \theta + 2n\pi, \varphi + 2n\pi)$ in case $0 < r < 1$. The locus $r =$ constant is an anchor ring and encloses the origin. You can readily convince yourself that there is no sphere enclosing the origin and hence that the origin is a point which has no neighborhood of the sort that exists in the Euclidean or Riemann geometries.

A corresponding line singularity can easily be defined in a four dimensional manifold and may well turn out to be a promising candidate for consideration as the world line of an ultimate particle of some sort. It has an extraordinary degree of indestructibility, and the paths that can be drawn in its neighborhood fall into discrete classes in a most suggestive way. It is not at all impossible that this or some other type of analysis situs singularity will enable us to maintain the continuity of space and yet take account of the discontinuous phenomena that are being observed.

Suppose, however, that it should turn out to be necessary to assume some sort of a discontinuous space. This would have at least one effect that would be pleasing to some of us. It would upset a great many of the cosmological speculations of the present era. In particular it would do away with that depressing view which is so often presented to us of the future state of the universe, a dead, cold world at a uniform level of energy and entropy. It would also tend to prevent our following a light ray too far off toward infinity—or all the way round a closed path—whichever the case may be supposed to be.

In order to have a definite idea of a discontinuous space-time, let us consider a modular case, *i. e.*, a space-time defined by four coordinates (x, y, z, t) which are whole numbers reduced modulo P, and let us suppose that P is an enormously large prime. The number system, modulo P, is one in which every rational operation can be carried out. Let us set a portion of these numbers into correspondence with the ordinary number system of analysis in the following manner: Let k be a fixed number which is small in comparison with P and yet large in comparison with the numbers used in

physics and astronomy; and let every rational fraction p/q in the modular number system for which p and q are less than k, correspond to the number p/q of the ordinary number system.

This correspondence between the number systems determines an analogous partial correspondence between the modular space-time and the ordinary space-time, by the expedient of letting the event (x, y, z, t) of the modular space-time correspond to the event (x, y, z, t) of the ordinary space-time, provided that the coordinates are all numbers which correspond.

If we wish to distinguish physically between the two space-times it is obvious that we must succeed in identifying an event in the one which does not have a corresponding event with the same coordinates in the other. This possibility can be obviated for all experiments that have hitherto been made by simply choosing k and P very large.

Nevertheless, if P is finite, the ordinary geometry, mechanics and electromagnetism are only a sort of approximation to the underlying modular geometry, mechanics and electromagnetism. They do not state actual theorems but only approximate results of a validity limited by the number k. For example, when we say that an event (x, y, z, t) is between two events (a, b, c, t) and $(\alpha, \beta, \gamma, t)$ we mean that $x = a + \lambda(\alpha - a)$, $y = b + \lambda(\beta - b)$, $z = c + \lambda(\gamma - c)$, where λ is less than 1 and expressible in the form p/q with q less than k. If we managed to subdivide the interval between the two events more than k times we should presently find that we were no longer between the two original events, but somewhere outside. For in the modular space-time there is no absolute system of order relations. We only have a partial system of order relations based on the correspondence limited by the number k.

It is for this reason that there are no absolute inequalities of the sort that appear in ordinary mechanics, and that no statements can be made which apply to unlimited amounts of space or of time or which require more than a limited subdivision of space and time. Hence the speculations to which I referred above about the ultimate fate of the universe, or about its distant parts, become impossible. Indeed, it becomes impossible to formulate the questions which these speculations purport to answer.

But if the current geometry and mechanics can be fitted so exactly to a space-time of so utterly different a character as a modular one, there are doubtless many other types of discontinuous space-time to which they can be equally well fitted. The moral with regard to all speculation which goes beyond the reach of experiment is obvious. But if it should be found that one of these discontinuous space-times fitted experimental results better than the continuous one, the situation might be radically altered.

Let us, however, apply our moral to ourselves and let these idle speculations go no further. Instead, let me urge once more the importance of further studies of the foundations of the classical branches of mechanics. It is true that the new conceptions of space and time are so varied as to have in common not much more than the idea that it is possible to characterize natural phenomena in an orderly way by means of sets of numbers. This is about as much as all experimental physicists and mathematicians would accept dogmatically. It is also true that elementary geometry and mechanics lay down a very particular system of rules according to which the sets of numbers are to be applied to phenomena. But these rules are such as our everyday experience has made second nature to us, for the experiments confirming them, although crude, are being continually repeated. Moreover, the rules are so good that they can be used in almost any theory as the preliminary way of assigning the coordinates from which the final coordinates can be calculated by variational methods. New theories are very apt to function merely as differential corrections to old ones.

Hence there need be no fear that further work devoted to perfecting the classical theories will be wasted. They will continue to be the instruments by which the vast majority of the facts of science are classified and to be regarded as the necessary preliminaries to the more esoteric theories. Those who have a taste for logistic work may therefore be urged wholeheartedly to devote their attention to formulating the postulates of the classical theories. There also seems to me to be a possibility of simplifying and modernizing the methods used

in these theories and of extending the results by bringing in more of the modern methods of mathematics, but that is not the present subject of discussion. What I wish to emphasize now is the need of logistic studies which will make it possible to say more definitely than is yet possible in this field what is assumed, what is proved, and how the group of theorems and definitions hang together. Incidentally, I would propose that the number of undefined terms be made large, rather than as small as possible, for whenever we introduce a new undefined term we separate off a group of theorems in which this term appears. Thus the undefined terms should be so chosen as to subdivide the science into divisions which are convenient both for mathematical and for physical purposes.

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PASTEUR, THE MAN[1]

PASTEUR has told us that scientific understanding comes to the "prepared mind." In reading the splendid "Life of Pasteur" written by his son-in-law, Vallery-Radot, as well as the more recent tributes by Duclaux and by Descour, one is impressed by the lack of detail as to how Pasteur's own mind became "prepared." The story has lately been told in greater detail by Marc Tiffeneau.[2] Pasteur, as everybody knows, was the son of a tanner who had been a soldier under Napoleon. Pasteur entered the École Normale at Paris when he was twenty-one years old, and graduated three years later in 1846. He became a demonstrator (agrégé préparateur) in chemistry, a position which had just been established in order to allow young men to continue their laboratory researches instead of exiling them to provincial professorships. About the same period, in the year 1845, Auguste Laurent left the chair of chemistry at the University of Bordeaux, which he had occupied since 1838, because he did not find there sufficient opportunity for research. Arriving in Paris, he accepted the offer of a new laboratory in the École Normale, and it was not long before Laurent recognized the exceptional character of his young assistant, Pasteur, an ardent worker and a brilliant thinker. Laurent was at this time thirty-eight years old. He was the son of simple French peasants; he was born, lived and died poor. When twenty-two years of age he graduated as engineer of mines and later became the assistant of Dumas, who taught him the principles of organic analysis. His doctor's thesis considered the doctrine of chemical substitutions, which is one of the pillars of the atomic theory, and the thesis described specifically the action of chlorine on organic compounds. He and his inseparable friend, Gerhardt, were the real founders of the atomic theory. Laurent now suggested to Pasteur the subject of his thesis, which also involved the then great controversy of chemical substitutions. On August 23, 1847, Pasteur presented for his doctorate a paper entitled "Research into the saturation capacity of arsenious acid. A study of the arsenites of potash, soda and ammonia." Pasteur herein writes regarding Laurent that he had been "enlightened by the kindly advice of a man so distinguished both by his talent and by his character."

And on another occasion he says, "Laurent's lectures are as bold as his writings, and his lessons are making a great sensation among chemists." For Laurent, in 1846, gave the first course on "chemical anatomy" under the Faculty of Medicine of Paris to crowded classrooms, and here for the first time enunciated the atomic doctrine before medical students.

Laurent, having been trained as a mining engineer, had a remarkable knowledge of crystallography, and in 1845, according to Tiffeneau, had shocked his colleagues by declaring that substances which were isomeric could crystallize in different systems.

When Laurent left the laboratory in 1847 Pasteur was already the master of his technic. Shortly thereafter Pasteur became interested in the relation between chemical structure and the power to rotate polarized light, from which arose his celebrated studies upon the molecular dissymmetry of tartaric acid published in 1848.

To Biot, an old man of seventy-four who

[1] An address delivered on the centenary of the birth of Pasteur on December 27, 1922, before a meeting of the Federation of Societies for Experimental Biology held at Toronto, Canada.

[2] Tiffeneau, M.: *Bull. Soc. française de la histoire de médicine*, 1921, 15, 46.

had first applied the polariscope in the study of the rotation of glucose solutions, he demonstrated that by picking out right and left-handed hemihedral crystals of tartaric acid and making of them separate solutions, these solutions were respectively dextro- and levo-rotary. Pasteur relates the outcome in these words, "Then, very visibly affected, the illustrious old man took me by the arm and said, 'My dear child, I have loved science so much all my life that this makes my heart throb.'"

In one of his letters Pasteur exclaims, "I, who did so love my crystals."

It has seemed worth while to consider how the youthful, highly receptive mind of Pasteur struggled out of its native environment to receive the endowment obtained in Paris from intellectual association with the best the world had to offer. While inheritance from good germinal protoplasm may be an essential factor of intellectual power, yet in science the training of the mind at the hands of a master, so that the fruitful knowledge of the time is sown in younger and not yet worn-out mental soil, is the secret of advance from generation to generation. Pasteur himself sowed this seed in the minds of Calmette, Chamberland, Roux and Metchnikoff. A colonial dependency of Great Britain having half the population of the present city of New York produced Benjamin Franklin and Benjamin Thompson at the same time that it produced Washington, Alexander Hamilton and John Jay. But the minds of Franklin and Thompson were stamped with manifold European contacts.

The scientific mind is more than a good intellectual inheritance, more than that a great master has had it in charge, and Pasteur has thus described it: "The illusions of an experimenter form a great part of his power. These are the preconceived ideas which serve to guide him. Many of them vanish in the long path which he must travel, but one fine day he discovers and proves that some of them are adequate to the truth. Then he finds himself master of facts and of new principles, the application of which sooner or later bestows their benefits."

United with this imaginative power went prodigious industry. Pasteur was not one of those who sat all day at his desk and expected others to accomplish the physical work of the laboratory in the execution of his thoughts. This man at least did not seek to avoid physical drudgery in the simple surroundings of the humble French laboratories of his day. Reflecting on the huge sums spent on the Opéra, he writes to the official *Moniteur*, "I implore you take some interest in those sacred dwellings meaningly described as laboratories." The lesson taught by the consecration of his life to a life of labor in a laboratory is that the true laboratory worker is a laborer and not a loafer.

Pasteur shows his character in writing a wonderful tribute to Claude Bernard at a time when the latter was very ill, causing Bernard to remark that the article "paralyzed the vasomotor nerves of my sympathetic system and caused me to blush to the roots of my hair." One academician wrote of this affair, "The public will learn, among other things, that the eminent members of the academy admire and love each other, sometimes with no jealousy."

Pasteur, as the world knows, was convinced that the process of alcoholic fermentation was bound up in the life of the yeast cell, a doctrine violently combatted by Liebig "with a vigor and obstinacy characteristic of the man and inversely proportional to the strength of the argument" (F. J. Moore). The discovery later by Buchner that a zymase could be expressed from yeast which would produce alcoholic fermentation, does not invalidate Pasteur's thesis, for Rubner has shown that ninety-five per cent. or more of the activity of yeast is actually due to the metabolism of glucose within the living cell.

A very human characteristic develops in the story of the life of Pasteur when we are told of his dismay and distress to find, after the death of his true and trusted friend Claude Bernard, some notes which threw doubt upon Pasteur's interpretation of alcoholic fermentation! How often this human weakness occurs! I have sat next to a member of the Federation of Societies for Experimental Biology at a time of the dismemberment of one of his theories at the hands of another member and heard the agonizing cry, "I thought X was a friend of mine." Heart-breaking and human though this be, it is logically absurd to build friendship upon the basis of a similarity of intellectual metabolism.

It is not necessary here to refer to Pasteur's services to the world in the subjects of bacteriology and immunology. Suffice it to say that they have saved to France alone many times the cost of the Franco-Prussian war of 1870. And this transforming work of Pasteur may be contrasted with an early statement of Liebig, expressed in 1845, "As to the opinion which explains putrefaction of animal substances by the presence of microscopic animalcules, it may be compared to that of a child who would explain the rapidity of the Rhine by attributing it to the violent movements of the numerous mill-wheels at Mayence."

Finally, let it be remembered that Pasteur was a deeply religious man. On Armistice Day, 1918, the London crowd at first instinctively surged to Buckingham Palace, where lives the king, and then instinctively to St. Paul's Cathedral. Pasteur puts it thus: "The idea of God is a form of the idea of the Infinite. As long as the mystery of the Infinite weighs on human thought, temples will be erected for the worship of the Infinite, whether God is called Brahma, Allah, Jehovah or Jesus; and on the pavement of those temples men will be seen kneeling, prostrated, annihilated in the thought of the Infinite."

He himself lived a life closely approaching the infinitely valuable.

GRAHAM LUSK
CORNELL UNIVERSITY MEDICAL SCHOOL

SCIENTIFIC EVENTS

THE PAN-PACIFIC SCIENCE CONGRESS

ON the representations of the Australian National Research Council, it has been decided to hold the next Pan-Pacific Science Congress in Australia in 1923. The meeting will commence at Melbourne on August 13 and terminate at Sydney on September 3. The event will be an important one in the history of Australian and Pacific science. The commonwealth government through its prime minister, Mr. W. M. Hughes, has decided to extend its support to the meeting, and has agreed to provide the sum of £5,000 towards the cost. Invitations to send representatives have been issued by the commonwealth government to the various countries bordering the Pacific or having interests therein, while the Australian National Research Council is inviting a large number of leading scientific men who are interested in Pacific matters to attend and take part in the proceedings.

The first Pan-Pacific Science Congress was held in Honolulu in August, 1920, and the work accomplished on that occasion served to show the great value and importance of such meetings between representatives in and around the Pacific. It is proposed that these congresses so successfully inaugurated at Honolulu should be continued triennially. In addition to the benefit arising from the interchange of scientific thought, a mingling of leaders of science will tend to the bringing about of a better understanding between the peoples of the Pacific.

Among the office bearers are the following:

Australian National Research Council: Professor Orme Masson, The University, Melbourne, *president;* R. H. Cambage, Royal Society, Sydney, *honorary secretary-treasurer;* Professor A. C. D. Rivett, The University, Melbourne, *joint honorary secretary.*

Pan-Pacific Committee: Professor Sir Edgeworth David, The University, Sydney, *chairman;* E. C. Andrews, Mines Department, Sydney, *honorary secretary.*

The tentative list of subjects for papers and discussion is as follows:

A. *Agriculture and Veterinary Science:* Soil problems, climate in relation to crops, plant pathology and plant breeding. Diseases of livestock in the Pacific region: Methods of eradication and control.

B. *Anthropology and Ethnology:* Polynesian and Melanesian races, Australian aborigines, totems, languages, folk-lore, anatomy.

C. *Biology:* General plant distribution in the Pacific; floras of island groups and of individual islands. Insects harmful to the planter and farmer. Role of insects in transmitting disease and the control of weed pests. The distribution of animals. Fisheries.

D. *Geography and Oceanography:* Marine currents, continental shelves, charting in the Pacific.

E. *Geology:* Coral reefs, glaciation, structure of the Pacific region, Carboniferous and Permian problem, correlation of Cretaceous and Kainozoic sediments in Pacific, mineral resources, vulcanology, geological surveys.

F. *Hygiene and Climatology:* Mining hygiene, ventilation, dust prevention. Tropical diseases,

hookworm, malaria. Climate in its relation to human efficiency.

G. *Physics:* Isostasy, arc of meridian in Australia, longitude by wireless, weather cycles and weather forecasting.

INTERNATIONAL CONFERENCE OF PHYTOPATHOLOGY AND ECONOMIC ENTOMOLOGY

ANNOUNCEMENTS have recently been received in this country inviting plant pathologists and entomologists to attend an International Conference of Phytopathology and Economic Entomology in Holland during June, 1923. Arrangements for this conference are in charge of a committee composed of Professor Dr. H. M. Quanjer, Professor Dr. Johanna Westerdijk, N. van Poeteren, T. A. C. Schoevers, J. Hudig, Dr. E. van Slogteren, G. Kruseman, J. C. Dorst, J. G. Hazeloop, E. H. Krelage and J. H. van Straaten van Nes.

The committee invites those who wish to read papers or bring up for discussion urgent questions on plant diseases or insect pests. The titles and short abstracts of the papers or questions for discussion should be sent in advance to the secretary, Mr. T. A. C. Schoevers, Villapark 8, Wageningen. The official language of the conference will be English, but papers can be read and discussion held in either English, French or German.

The conference will be held from June 25 to June 30, 1923, and participants are invited to arrive at Wageningen on Sunday, June 24. The following program has been arranged:

Monday, June 25: Presidential address of welcome and lecture on plant diseases as seen from the standpoint of general pathology. Demonstration of experiments, especially on potato diseases. In the afternoon and evening addresses, papers and discussions.

Tuesday, June 26: Address by Mr. van Poeteren on organization and methods of the Dutch Phytopathological Service. Discussion on international laws and requirements. In the afternoon demonstrations of some methods of control of pests and diseases as practiced in Holland, *e. g.,* the furrowing-wheel to destroy leather-jackets, control of American gooseberry mildew, of smut and stripe in grain crops, etc. Evening meeting: Addresses, papers and discussions.

Wednesday, June 27, and Thursday, June 28: Trips through the country. To prevent congestion of the program, participants are requested to subdivide into those interested in agriculture and those interested in horticulture. On Wednesday morning the first group will travel by rail to Friesland, where farms and selection-fields of potatoes are to be visited; next day Groningen Agricultural Experiment Station, address of Mr. Hudig on diseases of crops on alkaline and sour soils, and visit to Mr. Hudig's experiments. Visit to the Experimental Farm of the Groningen Seed Growers' Association.

The second group will visit first the nurseries of Boskoop and Aalsmeer, situated in a typical Dutch country region below sea level; thereafter visit to the bulb-growing districts near Haarlem. Dr. v. Slogteren will address the company and give a demonstration on modern methods of combatting some bulb diseases, *e. g.,* eelworm. This trip will end with a visit to the early potato districts of North Holland, where selection is practiced.

It would be possible to form a third group for visiting other centers of culture, such as the Westland, the most important district growing vegetables and fruit under glass; afterwards the orchards in North Holland and the early potato fields in the same district might be visited.

Friday, June 29: Meeting of Baarn; address of Professor Westerdijk on the cultivation of parasitic fungi and demonstration of research work. Afternoon devoted to discussions and inspection of the international collection of fungi-cultures. This meeting will be continued during the evening for addresses, papers and discussions, and to Saturday morning, if desired.

Saturday, June 30: In the afternoon of that day the conference will leave for the Hague, for an informal meeting at the office of the minister of agriculture. Thereafter the committee will entertain all participants at dinner in the bathing resort Scheveningen.

All scientific men planning to attend the conference should notify Secretary Schoevers in order that proper arrangements may be made for transportation and entertainment.

APPALACHIAN FIELD TRIP

MEMBERS of the Department of Geology in the Mississippi Agricultural and Mechanical College in the late summer of 1922 completed an Appalachian field trip in two automobile trucks, touring parts of eight states and covering more than 2,000 miles in direct travel.

From the college to Tuscaloosa, the whole of the Cretaceous was crossed. At various places from Birmingham, through Anniston, Gadsden,

Chattanooga, Cleveland and Knoxville, to Jellico, numerous stratigraphic sections of the Paleozoic beds were measured and many structure sections of the Southern Appalachians were made. On a side trip from Cleveland to Ducktown, Copper Hill and beyond, Archeozoic and Proterozoic beds were examined. In addition, coal, iron, zinc and copper mines; dolomite, limestone, slate and marble quarries; and iron, aluminum, and acid (industrial) plants were visited.

Across central Kentucky, the Blue Grass region of horizontally-bedded limestones was traversed. From Cincinnati to Columbus and thence across southeastern Indiana to New Albany, the glaciated area was studied. In western Kentucky, from Louisville to Mammoth Cave and Bowling Green, the cave and sink topography was almost continuously under observation. Thence the beautiful Blue Grass region of Tennessee, the phosphate mines about Nashville, the Wilson Dam power project at Muscle Shoals, and finally home.

From seats of vantage in the trucks, which passed across the plains, down into the valley depths, and over the mountain tops, the ever present and continuous opportunity was one of unobstructed vision. Under such conditions on this trip from a Gulf state to a Great Lakes state and back over a different route, obviously the great thing was the study of some of the larger phases of geology. Especially is this true of that part which may be termed geologic control of industrial environment. It was the major feature of the trip.

The tour aroused considerable interest among members of geologic departments of a number of universities and in deference to their requests it may be appropriate to mention something about the equipment, expense, etc. The two trucks were one-ton, high-gear Fords, equipped with bodies especially designed for field trips about the college. Three of the four seats were removed from one of the cars and in it the baggage and camp equipment were carried, while the other one was used as a passenger car. Only the maintenance (gasoline, repairs, etc.) cost, which scarcely exceeded the original individual deposit of twenty-five dollars, was charged to the members of the party, consisting of two instructors, Professors Morse and Vestal, and ten students. The living expense was approximately the same amount.

W. O. M.

REPORT OF THE DIRECTOR OF THE NEW YORK BOTANICAL GARDEN

IN his annual report to the board of managers Dr. N. L. Britton, director-in-chief of the New York Botanical Garden, stressed the need of funds to more completely develop the usefulness of the garden, commented on the greatly increased interest in plants of all kinds and spoke of the difficulty of preserving the beauty of the natural features of the reservation with the constantly growing number of visitors and with what he characterized as insufficient police supervision.

The following officers were elected to the Board of Managers: Dr. Frederic S. Lee, *president;* Henry W. de Forest and Frank L. Sturgis, *vice-presidents;* John L. Merrill, *treasurer;* Henry de la Montague, Jr., *assistant treasurer;* Dr. N. L. Britton, *secretary.* For the last three years Dr. Lee has served as vice-president of the board.

Dr. Britton's report deals with the progress made in the improvement of the grounds, in the increase, development and study of the collections of plants, specimens and books and in educational and scientific work. A somewhat insufficient force of gardeners and laborers also has militated against the more perfect maintenance of the older plantations.

The collections are now among the largest and most important anywhere, but their extended usefulness and increase, the further development of the reservation of nearly 400 acres, the completion of the buildings and the extension of educational and scientific work require more funds than as yet have been made available.

Approximately 16,000 kinds of plants have been in cultivation during the year, about 9,000 of which were under glass and 7,000 outdoors. The increase of the record over 1921 is largely covered by the planting in the iris garden and the new rock garden. The garden had the cooperation of the American Iris Society in the work in the iris garden; Mrs. Mortimer J. Fox and T. A. Havemeyer gave their aid in increasing the collections of lilies, Mr. Havemeyer also

contributing a valuable series of lilacs. Messrs. Bobbink and Atkins, in continued cooperation with the Horticultural Society of New York, gave 2,700 plants for the rose garden.

In the rock garden the arrangement of gravel and top soil and the planting of over 400 kinds of plants, including over 5,000 individuals, have been largely the work of Dr. E. B. Southwick, custodian of herbaceous grounds.

The rearrangement of the cactus collection and the improvement and development of the southern part of the garden reservation along Pelham Parkway also are dealt with in the report. The latter was carried forward at two points. One of these lies east of the mansion approach entrance, where about 350 feet of the boundary wall and fence have been built. The other area lies between the iris garden entrance and the Bronx River, where some 400 feet of the boundary wall and fence, including piers for the hemlock grove path entrance, built from the bequest of Emma Chambers Jones, grading and drainage have been done and some 400 feet of path system partly built and a screen of trees planted.

Appended reports were made by Dr. H. A. Gleason, assistant director; Dr. John K. Small, head curator; Dr. Murrill, supervisor of public instruction; Kenneth R. Boynton, head gardener; Dr. A. B. Stout, director of laboratories; Dr. Henry H. Rusby, honorary curator of the economic collection; Mrs. N. L. Britton, honorary curator of mosses, and others of the staff.

SCIENTIFIC NOTES AND NEWS

At the recent meeting of the Geological Society of America, at Ann Arbor, David White, who recently retired as chief geologist of the United States Geological Survey, was elected president. The following vice-presidents were elected: William H. Hobbs, William H. Emmons, T. Wayland Vaughan, Edgar T. Wherry.

Professor M. F. Guyer, chairman of the department of zoology of the University of Wisconsin, was elected president of the American Society of Zoologists at the recent Boston meeting.

The Society of American Bacteriologists has elected the following officers for 1923: Professor E. G. Hastings, University of Wisconsin, *president;* Major A. Parker Hitchens, U. S. Army Medical School, *vice-president;* and Dr. J. M. Sherman, U. S. Department of Agriculture, *secretary-treasurer.*

At the annual meeting of the American Physiological Society at Toronto, December 27, 28, and 29, 1922, the officers elected were: Professor Anton J. Carlson, University of Chicago, *president;* Professor Charles W. Greene, University of Missouri, *secretary;* Professor Joseph Erlanger, Washington University, St. Louis, *treasurer;* Professor Arno B. Luckhardt, University of Chicago, and Professor John R. Murlin, University of Rochester, were elected to the council.

Dr. Elsie Clews Parsons has been elected president of the American Ethnological Society, New York.

Secretary Hoover has designated Dr. Fay C. Brown, assistant director of the Bureau of Standards, to be acting director.

Sir William H. Bragg, Quain professor of physics in the University of London, has been elected a corresponding member of the Paris Academy of Sciences in the section of physics.

Professor J. Schur, mathematician of the University of Berlin, has been elected a member of the Berlin Academy of Sciences.

As Dr. Chauffard, professor of clinical medicine at the School of Medicine, who has been the vice president of the Paris Academy of Medicine, has become president for the year 1923, in accordance with the constitution, the academy has elected Dr. J. A. Doléris vice president. Dr. Doléris is an honorary obstetrician to the hospitals of Paris. The academy also elected Dr. Souques as annual secretary, and Professors Pouchet and Schwartz as members of the administrative council.

Richard V. Ageton, of the Bureau of Mines, who has been doing examination work for the War Minerals Relief Commission, is acting as assistant chief mining engineer of the bureau.

Dr. P. V. Wells of the optics division of the Bureau of Standards has resigned to take up research work for the E. I. du Pont de Nemours Company, Parlin, New Jersey.

Jerome Alexander, M.Sc., has now an office in the Chemists Building, New York City, as

consulting chemist with special reference to colloid chemistry and its applications.

DR. ROBERT M. YERKES, A.M., director of the Division of Personnel Administration of the National Research Council, reported for duty on December 3 to the commanding officer of the Army War College for three weeks' service in connection with army personnel methods. Since Professor Yerkes's discharge from the army he has been a lieutenant-colonel, Officers' Reserve Corps, assigned for duty in case of need to the Division of Operations of the General Staff.

DR. GANO DUNN has been appointed by the council of the Institution of Electrical Engineers of Great Britain to be local honorary secretary of the institution for the United States in the place of the late Mr. George G. Ward.

VERNE L. HAVENS, director of the *Ingenieria Internacional,* has been made permanent secretary of the International Engineering Congress, composed of engineers of North America and the Latin-American republics.

THE Institute of American Meat Packers, Chicago, has appointed a committee consisting of W. D. Richardson, chief chemist, Swift & Company, Paul Rudnick, chief chemist, Armour & Company, and L. M. Tolman, chemical director, Wilson & Company, to select a suitably qualified chemist for the position of director of scientific research of the institute.

DR. BAILEY WILLIS, emeritus professor of geology, Stanford University, sailed for Chile on January 11 to investigate the evidence of the recent earthquake, in response to an invitation sent to the Carnegie Institution of Washington through the Chilean Embassy.

HERBERT E. GREGORY, professor of geology at Yale University and director of Bishop Museum, Honolulu, is returning to Hawaii on February 1 to remain until October.

MR. CHARLES W. HOY, of the Smithsonian Institution, left Washington December 15 for a two years' trip in Central China, in the basin and mountains of the Yang-tse, devoting most of his time to collecting mammals, birds and fishes.

PROFESSOR OSWALD VEBLEN, of Princeton University, has been granted leave of absence for the second semester of 1922-23 and is to spend it in Europe.

DR. WALTER G. CADY, professor of physics at Wesleyan University, has been granted leave of absence for the second half of the academic year. He plans to go abroad visiting laboratories in Italy, France and England.

DR. HENRY B. WARD, professor of zoology at the University of Illinois and national president of the Society of Sigma Xi, recently delivered the annual Sigma Xi lectures at the Missouri and Kansas chapters and at the Sigma Xi Club at the University of Oklahoma, on the following subjects: "The factors which control and direct the migration of the Pacific salmon" and "The struggle of man with the life of the wilderness in North America."

DR. PHILIP A. SHAFFER, professor of biological chemistry at Washington University, will deliver the sixth Harvey Society lecture at the New York Academy of Medicine, on Saturday evening, February 10. His subject will be "Antiketogenesis: its mechanism and significance."

THE Harvard Engineering Society held its annual dinner in New York on February 1 at the Harvard Club. President C. R. Richards of Lehigh University, Dr. Charles P. Berkey, Columbia University, and Albert Palmer, president of the undergraduate section of the society, were the principal speakers.

PROFESSOR M. I. PUPIN, of Columbia University, lectured before the New York section of the American Institute of Electrical Engineers, on January 19, on "The story of modern physics."

PROFESSOR GEORGE C. WHIPPLE, of Harvard University, gave on January 6, 13, 20 and 27 at the Wagner Free Institute of Science four lectures on "The philosophy of sanitation."

DR. A. E. RENNELLY, professor of electrical engineering at Harvard University and the Massachusetts Institute of Technology, on January 11, gave a lecture before the Franklin Institute of Philadelphia on "The principles of electrical vibration instruments."

DR. MARSTON T. BOGERT, professor of chemistry in Columbia University, gave a lecture at Connecticut College for Women, New London,

Conn., on January 23 on "Synthetic dyestuffs and their bearing on the life of the individual and of the state." Other lectures on science, scheduled for March 20 and 27, are "The pursuit of the atom," by Professor Frederick A. Saunders of Harvard University, and "Psychology and democracy," by Professor Robert S. Woodworth of Columbia University.

A GIFT of $11,000 has been made to Lafayette College to establish the "Joseph Johnson Hardy Memorial Fund" as a tribute to the services of the late Professor Hardy, for forty-five years teacher of mathematics at Lafayette. The income is to be divided at each commencement equally among the five members of the faculty oldest in point of continuous service, without regard to rank, so long as engaged in full-time teaching.

AT the Pasteur centenary meeting held at the New York Academy of Medicine on January 10, the president of the academy, Dr. George David Stewart, announced that the rights to Sacha Guitry's play "Pasteur" have been acquired for Henry Miller. The play will be presented by the Charles Frohman Company, Henry Miller taking the title rôle. The English version of the play has been made by Arthur Hornblow, Jr.

A MONUMENT to Pasteur is to be erected at Strasbourg, subscribed by men of science and learning throughout the world. The monument, which is the work of the Lyons sculptor, Larivée, will be placed in front of the university, near that of Goethe. It is an obelisk 10 feet high with a medallion of Pasteur and allegorical figures on either side. The International Exhibition of Hygiene, which is being prepared at Strasbourg, will cover more than 12,000 square yards. Different sections will show the influence of Pasteur's work on the life of man and animals, agriculture and industry. A Pasteur Museum will complete the exhibition.

DR. JOHN ASBURY ELLIOTT, professor of plant pathology at the University of Arkansas and pathologist in the Arkansas Agricultural Experiment Station, died on January 18 at Washington, D. C., where he was expecting to spend the month of January with the Department of Agriculture in plant disease survey work. He died of pneumonia as a complication following bronchitis, contracted while attending the Boston meeting, and was interred at Washington, D. C.

PROFESSOR S. S. KELLER, head of the department of mathematics of the Carnegie Institute of Technology, died in Baltimore on January 12. Professor Keller had been a member of the faculty of the institute for the past seventeen years.

PROFESSOR JOHN W. CALDWELL, *emeritus* professor, formerly head of the department of chemistry in Tulane University of Louisiana, died on January 2 at his home in New Orleans.

DR. JOHN H. LARKIN, associate professor of gross pathology at the New York Homeopathic Medical College and Flower Hospital, died on January 17 at the age of fifty-three years.

DR. K. KERTESZ, of the Hungarian Museum, the well-known writer on Diptera and the author of the great catalogue of the Diptera of the world, died on December 28.

THE United States Coast and Geodetic Survey has received a cablegram from Leyden, Holland, announcing the death in that city, at a very advanced age, of Dr. H. G. van de Sande Bakhuyzen, formerly director of the Leyden Observatory. For many years Dr. Bakhuyzen was permanent secretary of the International Geodetic Association.

THE death is announced of the eminent Italian scholar, Dr. Antonio Nobile Favaro, professor of projective geometry in the University of Padua. Professor Favaro was born on May 21, 1847, at Padua, where also he died on the thirtieth of September, 1922. He is known through the national edition of Galileo's works which he edited in twenty quarto volumes, and by his many historical papers dealing with the life and times of Galileo. Among his most recent contributions is a history of the University of Padua, written for the celebration of the seven hundredth anniversary of this institution, the oldest, not only of the Italian universities, but of all existing universities.

PRESIDENT HARDING has withdrawn from settlement three groups of prehistoric towers in southwestern Colorado and southeastern Utah. These are known as the ruins in Ruin

Canyon, Holly Canyon and Cool Spring House on Cajon Mesa. It is proposed that these groups be made a national monument.

THE agricultural appropriation bill, carrying $68,981,553, was passed on January 3 by the House of Representatives after Speaker Gillett had thrown out on a point of order a motion to send it back to committee with directions to include $360,000 for congressional free seed distribution.

AT the annual meeting in a joint program on the last day of the session of the societies composing the Federation of American Societies for Experimental Biology at Toronto, a very interesting scientific program consisting of ten papers on the newer discoveries of various laboratories in the United States and Canada, led by the laboratories of the University of Toronto, was held on the subject of the pancreas and the specific pancreatic secretion, insulin. At the annual dinner held on the one hundredth anniversary of the birth of Pasteur, December 27, 1922, lectures were delivered on the life and works of Pasteur by the following speakers: Sir Robert Faulkner, University of Toronto; Graham Lusk, Cornell University; Albert P. Mathews, University of Cincinnati; F. G. Novy, University of Michigan.

THE Cellulose Division of the American Chemical Society has been authorized as a permanent division of the society and wishes to enroll as members in the division all those who are interested in cellulose chemistry either from a scientific or practical standpoint. All members of the American Chemical Society wishing to become members of this division are requested to send their names and business connections together with one dollar for dues to the secretary, L. F. Hawley, Forest Products Laboratory, Madison, Wisconsin.

UNIVERSITY AND EDUCATIONAL NOTES

PLANS for a new chemical laboratory for the Johns Hopkins University, to be erected at Homewood, at a cost of about $600,000, have been completed. The details of the building have not been made public, but it is known that the type of architecture will conform to the colonial style of the Homewood group. Bids for contracts for the new $1,000,000 home of the Johns Hopkins School of Hygiene and Public Health, which will be on Monument and Wolfe Streets, as a part of the hospital group, will shortly be asked. The plans have been completed. This structure will be of Italian architecture of brick and stone, and is provided through a donation to the school by the Rockefeller Foundation.

A FUND amounting approximately to $3,800 has been subscribed in honor of Professor Appleton, of Brown University, to be known as the John Howard Appleton Lectureship Fund to provide annual lectures at Brown on pure or applied chemistry.

BROWN UNIVERSITY has received $50,000 from the estate of the late Robert P. Brown, to endow a professorship in biology. Albert Davis Mead, head of the department of biology in the university, has been appointed Robert Perkins Brown professor of biology.

DR. HARRY PRATT JUDSON, second president of the University of Chicago, holding that position for sixteen years, has resigned and will retire from active work on February 20. Dr. Ernest DeWitt Burton, head of the department of New Testament and early Christian literature and director of the libraries, has been elected acting president.

THOMAS B. BAINS has accepted a position as assistant professor of mining engineering at the University of Illinois.

HERBERT R. HANLEY has been appointed associate professor of metallurgy at the Missouri School of Mines.

DISCUSSION AND CORRESPONDENCE

BALANCING CHEMICAL EQUATIONS

IN the issue of SCIENCE for September 1 (page 258) there is an article describing an algebraic method of balancing chemical equations. The method, which assumes a knowledge of the formulas of the initial and final substances, consists in finding, algebraically, sets of values for the coefficients of the equations. The author seems to have discovered a nearly constant relation between the number of elements and of compounds represented in

the equation. To the writer the ratio does not seem to hold very strictly even in the equations cited in the articles; but this may be due to a lack of understanding on his part. When understood it may be assumed to be accurate, and may be useful and rapid in the hands of those whose minds readily run along mathematical channels. It may also be advantageous in commercial laboratories, where the end sought is simply the relative weights of materials taking part in reactions because, being mathematical, it suggests an element of certainty to the conclusions. It may be especially useful in those commercial laboratories where the workers have only a superficial knowledge of the principles underlying chemical changes and therefore can not, with certainty, apply chemical methods of balancing.

But where the end sought is a clear understanding of the principles of the subject the method described has in it, as in all mechanical methods, an element of danger, since it may lead the worker to the belief that the balancing of an equation is, *per se*, proof of a thorough understanding of the chemistry involved. To the writer it still seems uncertain whether the newer algebraic method has any advantage, either in certainty of conclusion or in rapidity of work, over the strictly chemical method of balancing. A comparison of the two methods may be made by considering the first equation introduced by the author of the article in question, *viz.*, the reduction of silver arsenate by the hydrogen produced by the action of zinc with sulfuric acid:

$$a\mathrm{Ag_3AsO_4} + b\mathrm{Zn} + c\mathrm{H_2SO_4} \rightarrow d\mathrm{AsH_3} + e\mathrm{Ag} + f\mathrm{ZnSO_4} - g\mathrm{H_2O}.$$

Since the equation shows that the salt is reduced to silver and arsine, it takes but a glance to see that for each molecule of the salt there is needed sufficient hydrogen (8 atoms) to combine with the four atoms of oxygen (forming 4 molecules of water) and additional hydrogen (3 atoms) to combine with the arsenic (forming one molecule of arsine). That is, 11 atoms of hydrogen are needed for each molecule of the salt. Since an odd number of atoms of hydrogen can not be made by the action of sulfuric acid on zinc the one molecule of salt must be multiplied by two, and these require 22 atoms of hydrogen (from 11 molecules each of zinc and sulfuric acid) and there are produced 6 atoms of silver, 2 molecules of arsine and 8 molecules of water. Thus the smallest coefficients necessary to balance the equation are easily found, and there is the added advantage that the principle and mechanism of the reaction are reviewed.

The other illustrations used by the author are as easily analyzed and balanced if there is kept in mind the additional thought that the salts behave as though they were composed of two oxides each ($2\mathrm{KMnO_4} \rightarrow \mathrm{K_2O}, \mathrm{Mn_2O_7}$ and $\mathrm{K_2Cr_2O_7} \rightarrow \mathrm{K_2O}, 2\mathrm{CrO_3}$), the latter oxide in each case being reduced to the lowest oxide. Finally all the oxides react with sulfuric acid to form sulfates.

In detail, two molecules of the permanganate must lose 5 atoms of oxygen and these combine with an equal number of atoms of the oxygen from 5 molecules of the hydrogen peroxide, forming five molecules each of oxygen and water. The three molecules of oxide ($\mathrm{K_2O}, 2\mathrm{MnO}$) then react with three molecules of sulfuric acid to form one molecule of potassium sulfate, two molecules of manganese sulfate and three additional molecules of water (eight in all). The equation can then be written with the proper coefficients.

The reduction of the dichromate is more complicated only in this, that two reducing agents are involved, both of which are assumed to be oxidized—an assumption which probably would not be verified by experiment.

This note is written, not to criticize the algebraic method of balancing equations, but rather as a caution to teachers (especially young and inexperienced teachers) and students who might adopt it as a means of partially solving a rather difficult teaching problem—the writing of equations. It might be a help in solving this problem, but only at the expense of most important and vital teaching points; for the proper writing of equations is not an end in itself, but only a means of enforcing important chemical facts and principles, of studying the mechanism of reactions, and of practicing clear chemical thinking. All mechanical methods of balancing equations disregard these important elements in education.

JAMES H. RANSOM

DECATUR, ILLINOIS

A "SPINDLING-TUBER DISEASE" OF IRISH POTATOES

INVESTIGATIONS by the writers have recently disclosed that a malady commonly designated as "running-long" or "running-out" is an infectious disease. It has been transmitted from diseased to healthy plants by means of tuber grafts, vine grafts, leaf-mutilation inoculation and plant lice. Proximity of healthy plants to diseased plants in the field increases the amount of infection. The tubers perpetuate the disease from year to year. In the absence of control measures the percentage of incidence in a given stock increases from year to year.

Plants infected late in the season may show no symptoms in their tubers or elsewhere. Plants infected early from the seed-tubers or otherwise have erect, spindling stalks, leaves that are smaller, more erect and often darker green than healthy foliage, and tubers generally more cylindrical, more spindling, more spindle-shaped and with more numerous and more conspicuous eyes than are the tubers from healthy plants or from plants apparently healthy but inoculated late in the season. The yield is reduced somewhat the first year in which the symptoms appear in the plants, and more in subsequent years from plants growing from spindling tubers. In view of the symptoms described, the term "spindling-tuber disease" is proposed.

Like other degeneration diseases of potatoes, this disease has been attributed in the past to senility, reversion and adverse conditions of weather, climate, soil and culture. Undoubtedly potato tubers often are poor-shaped because of other causes than this disease. It is also clear that diseased hills may produce some tubers not easily distinguished from commercially acceptable tubers. However, many of the losses due to poor tuber shape and to reduction in yield are to be attributed to the spindling-tuber disease, which is to be found in many varieties and in all percentages of incidence.

More detailed data on this and other degeneration diseases of the potato are being prepared for publication in a later paper.

EUGENE S. SCHULTZ
UNITED STATES DEPARTMENT OF AGRICULTURE

DONALD FOLSOM
MAINE AGRICULTURAL EXPERIMENT STATION

NICOTINE SULPHATE, AN EFFECTIVE VERMICIDE FOR SHEEP

EXPERIMENTS covering a period of three years of study on the control of the sheep stomach worm, *Hæmonchus contortur*, at the Storrs Experiment Station have resulted in the finding of an effective dosage for killing stomach worms.

The most effective agent used has been a 40 per cent. nicotine sulphate diluted with water. Ten cubic centimeters, or approximately two teaspoonfuls of the 40 per cent. nicotine sulphate in one quart of water, giving four ounces to adult sheep and two ounces to lambs. These treatments were used in 948 cases, and 161 animals have been slaughtered twenty-four hours after the treatment and only a few live worms have been found in the stomach, constituting an effective dosage in that thousands of worms are commonly found in a single stomach.

The treatment caused the death of five weak lambs. While the treatment staggers and even kills very weak animals, it can be used without danger to other sheep and lambs and one can be reasonably sure of the effectiveness of the treatment in contrast with the less efficient copper sulphate treatment that has been so universally recommended. In the experiments where the one per cent. copper sulphate was used, live worms were found in the stomach and stronger solutions caused severe burns. In cases where the three per cent. copper sulphate solution was used as a dosage, the mortality from the treatment was more than sixty per cent.

Twelve hours previous to the treatment, the animals were kept away from food.

GEORGE H. LAMSON, JR.
STORRS EXPERIMENT STATION

SWARMING INSECTS SIMULATING SMOKE

ON February 26, 1921, at 6:30 P.M., persons strolling about the main building of the University of Texas raised a fire alarm because of what appeared to them as a wreath of smoke issuing from the middle tower. The writer was unable to discover any fire within the tower but from the roof of the building could make out that the "smoke" consisted not of carbon particles but of insects. These were

issuing from a small hole under the tin and flying in a close swarm, gently blown back and forth in the breeze like a delicate streamer. The swarm played in this manner for about fifteen minutes and then seemed to return whence they came.

None of the specimens were recovered from this swarm, but there seemed to be no doubt that they were Tenebrionid beetles living in bat guano in the tower. The insects secured from the bat guano this year were kindly identified by Dr. Edwin C. Van Dyke as *Blapstinus pratensis*, Lec.

In this connection the following Associated Press dispatch as published in the Austin *American* June 5, 1922, is of interest:

CHICAGO, June 4.—Mosquitoes flying in such thick swarms that they were mistaken for smoke caused two fire alarms to be turned in early to-day.

Members of a truck company answered a call saying that the steeple of St. Michael's Roman Catholic Church was burning. The firemen saw what they at first supposed was a small cloud of smoke and they raised their extension ladders to fight the fire. When they mounted the ladder they encountered mosquitoes and were forced back. The same experience was met by members of another engine company called to the Zion Methodist Church in another part of the city.

The fact that these two swarms were encountered the same day gives ground for the suspicion that guano beetles, not "mosquitoes," were swarming from bat-infested belfries of the two churches. The participation of the majority of the members of a species in the same locality on the same day of the year is, of course, a common phenomenon. If this were not so, swarming as a reproductive function would lose its adaptive significance.

CARL HARTMAN

THE UNIVERSITY OF TEXAS

QUOTATIONS

A SUPER-UNIVERSITY

THE meeting of the American Association for the Advancement of Science in Cambridge fulfills in a way the vision which Franklin K. Lane had of a "super-university." In a letter written in his own hand on the day before he went on the operating table in May of 1921, he described this "place of exchange for the new ideas that the world evolves each year" as follows:

No faculty—but a super-university with all the searchers and researchers, inventors, experimenters, thinkers of the world for faculty. No students—but every man the world round interested in the theme under consideration welcome as a student without pay.

Except that the meeting in Cambridge was national in its personnel, it answered very well Mr. Lane's definition. Nearly all the departments of human knowledge were represented: chemistry, botany, anthropology, mathematics, physics, geology, geography, zoology, agriculture, psychology and the economic and social sciences. Those not included were represented in like meetings elsewhere. A thousand papers were presented, from Professor Edmund B. Wilson's on "The physical basis of life" and Dr. Bell's discussion of the smashing of atoms to a study of baldness and of the ideal stature of successful salesmen. Every paper meant research into the field of the unknown in man's environment and most of them pushed back by much or little the mystery that surrounds his existence or made friends for him of forces that before seemed hostile to his freedom or his life.

This meeting also gave the super-university "Faculty"—serving for very love of the truth itself in most cases—an audience that was generally competent to understand what was brought before it. And when the results are intelligently, intelligibly and accurately reported, as was done by the *Times*, the student body becomes larger than that of any university, larger even than that of the super-university conceived by Mr. Lane.

There is only one thing lacking, and that is a permanent exhibition of the yearly increments made by man's conquest of his environment so that the public may have an opportunity to see (so far as it can be visualized) "all that is new in science, philosophy, practical political machinery and all else of the world's mind products." If there could be a place for such permanent exhibition and illustration of the contributions for the year of scientific research and experiment and invention (and "why not in New York?" said Mr. Lane), the value of such meetings as that at Cambridge and in other parts of the world would be vastly increased.—*The Times*, New York.

PROBLEMS IN THE DETERMINATION OF PHYSICAL PROPERTIES

IN preparing for publication the data on physical properties of chemical substances, the editorial staff of *International Critical Tables* will find from time to time that important physical properties of substances of technical and scientific importance are missing from the literature. As fast as we become aware of missing data of this character, it is our policy to formulate research problems covering such missing data and to endeavor to interest chemists and physicists in undertaking the necessary investigations to supply the required data.

Most of the research problems formulated in this way will be suitable for bachelors' or masters' theses and in a few instances topics sufficiently broad to be suitable for doctors' theses will also be available. Many of them will be suitable for experimental problems in the ordinary laboratory courses in physical chemistry and physics. Thus, for example, the laboratory experiment covering the determination of solubility might to advantage deal with substances whose solubility is needed but is unknown. The average of the determinations made by a class of students, while not as accurate and reliable as the determinations made by a skilled investigator, will nevertheless be very valuable when they constitute the only data available on the subject. Moreover the average student will be more interested in a laboratory experiment the results of which are of actual value and worthy of publication than he would be in repeating for the *n*th time the measurement of a property of some system which has been measured many times before.

International Critical Tables will be glad to submit to interested instructors in universities and colleges lists of problems of this character and to advise as far as it can concerning suitable apparatus and methods of measurement. It may be possible also in some instances to secure moderate financial assistance to aid in the purchase of materials and apparatus for investigators interested in carrying out work of this character. The results of such work may be published by the investigator in any appropriate publication medium and they should also be reported in duplicate to the office of *International Critical Tables* on completion of the work.

A number of problems on the following subjects are available at the present date: Heats of combination: solid oxides; Fe compounds. Specific heats: brass; solid oxides; steels; oils and fats; petroleum products; metals; salts; Fe compounds; asphalts. Latent heats of fusion: brass; metals. Heat conductivity: steels. Latent heats of vaporization: petroleum products. Viscosities: industrial materials; solutions. Kinetics: rates of drying; hydrolysis of industrial materials; catalysis; transpiration of moisture; biochemical. Strength: industrial materials. Thermal expansion: steels; Fe compounds. Freezing-point-solubility diagrams: salts; acids; metals in water; soaps. Boiling points: solutions. Solubility of gases: in molten metals; in water. Chemical equilibrium; dissociation pressures at 1600° C. Electrical conductivity: metals; refractories. Properties of colloidal systems; industrial materials. Vapor pressures: metals; solutions. Specific rotatory power: gliadin. Index of refraction: solids. Density: certain organic compounds; solutions. Flash points. Surface tensions: solutions.

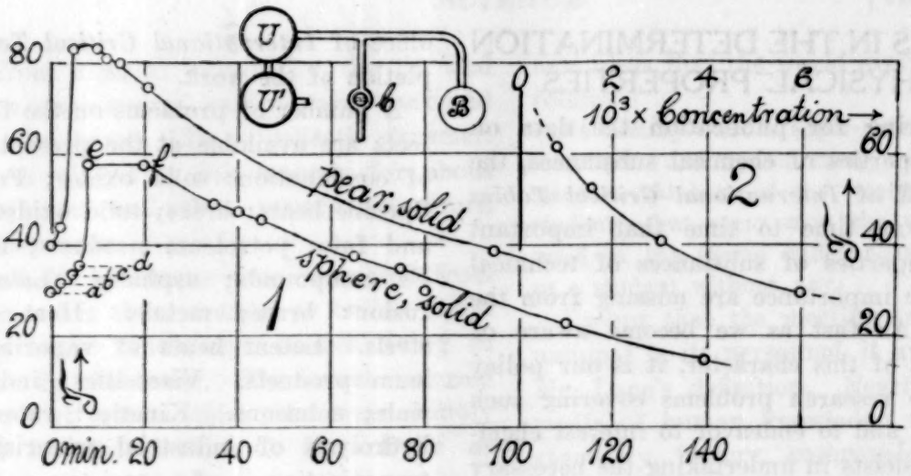
INTERNATIONAL CRITICAL TABLES
1701 MASSACHUSETTS AVENUE, N. W.,
WASHINGTON, D. C.

SPECIAL ARTICLES

GLUE BUBBLES

1. *Introductory.* The improvements which I have recently given to the interferometer U-gauge adapt it for measurements throughout larger intervals. The apparatus requires some experience on the part of the operator, but it gives absolute pressure values directly, and is quite robust, if not abused. Adding the pin hole valve as heretofore, I detected a hysteresis-like phenomenon in the telephone, according as an intermediate intensity of sound was reached from increasing or from decreasing intensity.

But the chief promise which the interferometer U-gauge seems to hold out is the measurement of such small but persistent pressure increments as arise in certain chemical and bacteriological processes. Here, how-



ever, one is liable to be misled by the inseparable temperature effect. For when one shank of the U-gauge is closed, it becomes an air or vapor thermometer, responding to much less than .001° C. per fringes. Hence though I ventured at some length upon experiments on gas absorption, vapor diffusion and solutional effects, it became increasingly obvious that the pressure increments and decrements obtained in a heated room were not trustworthy. I shall resume the work in the summer.

2. *Bubbles in general.* In case of bubbles of any kind (see diagrammatic insert, U-tube *UU'*, cock *C*, bubble *B*), these annoyances fall away and the pressure increment within the bubble is adjusted by the liquid film itself. It is of interest, therefore, to measure from pressures within the surface tension *T* of such films, passing by evaporation continuously from the liquid to the solid states. Of course, when the latter is reached, the bubble is no longer contractile and *T* ceases to be measurable; but one may at least reach a high state of viscosity. I have worked with sugar solutions, molasses and glue. In the former case, persistent bubbles are not producible; but by adding a drop of commercial soap solution to 10 cm.^{3} of sugar solution (1 gram in 10 cm.^{3}), bubbles 2 cm. in diameter or more are obtained. Occasionally one persists and dries out to a smooth, iridescent bubble of solid sugar, which may be detached and preserved. Again the sugar solution (or better plain distilled water) with one drop of liquid soap may be successively diluted, until the surface tension of pure water is closely approached. I passed in this way from *T* below 30 to *T* above 60 and could have gone further. It is interesting to note that when *T* is high, it rapidly falls off to lower values, possibly from the contamination of the surface of the film on exposure, but more probably, as I think, from the marshalling of the remaining colloidal molecules at the surface, with expenditure of potential energy.

3. *Glue bubbles.* These (common liquid glue diluted 5 to 10 times) are obtainable directly, since a diameter of 2 cm. or less is adequate. Nevertheless, if the mixture were expensive, the inevitable waste would be prohibitive. Fortunately it is not, and all that need be expended is patience, which is cheap. As above, bubbles are sometimes obtained which actually last indefinitely and these solid glue bubbles may be ultimately detached. I give the time record for two of them in Figure 1, in which surface tension *T*, is exhibited in the lapse of minutes. In the first of these the drop at the bottom of the bubble dried without further distortion, the bubble remaining spherical. In the second the drop blew itself out further and the bubble became symmetrically pear-shaped. In the case of the sphere, *T* at the beginning increased in *stages* shown at *a*, *b*, *c*, *d*, *e*, in the figure, the interval of persistence from *a* to *d* being less and less prolonged, while *e* is permanent. One would be inclined to consider these steps as successive phases passed through on the way to solidification; but the mottled color patterns on the bubble show that at most a complex of phases are temporarily in equilibrium. At *f*, after about 20 minutes, *T* apparently begins to decrease regularly.[1] It is obvious, therefore, that at *f* the bubble is practically solid, that most

of the water is gone and the compressed air within is now following, diffusing outward through the meshwork of colloidal molecules. The apparent decrease of T is thus spurious, merely implying that the solid bubble is continuous but leaky. This may be tested by opening the stopcock. After 4 hours no internal pressure is left. In case of the pear shaped bubble, the phenomenon was like the preceding, but much more rapid, so that stages of T could not be recognized. The T reached by the nearly solid bubble is very high, but a part of it must be referred to the change of shape specified.

In figure 2, I have shown the result of the successive dilution of the original liquid glue. The surface tension remains low and nearly constant until a dilution of the order of .005 is reached. Thereafter, with further dilution, T increases very rapidly to above 60 in the figure. Using the last (dilute) solution about a week later, bubbles were no longer obtainable, even after warming. Adding a drop of dilute soda solution, however, restored its bubbling virtue. On successive dilution by halving, this gave (in mean values) $T = 52$, 59, 63, 68, 73. With two observers, one to measure the diameter of the bubbles and the other to manipulate the interference fringes, even closer approach to a water surface would be possible. Though thick and colorless, the bubbles have to withstand an increasing capillary strain and like time and tide they tarry for no man.

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THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

SECTION G—BOTANICAL SCIENCES

Vice-president and chairman, Francis E. Lloyd.

Retiring vice-president, Mel. T. Cook.

Secretary, Robert B. Wylie; State University of Iowa, Iowa City, Iowa.

(Report by R. B. Wylie)

From the viewpoint of the botanists the Boston meeting was one of the best in recent years. While the number of members in attendance from the interior and from the west was somewhat smaller than at the Chicago meeting, there were proportionately more of the eastern workers in attendance. The botanical programs presented an imposing array of titles. Something over two hundred papers and addresses were scheduled in the various meetings for plant workers.

The extent of the program as well as diversity of interest compelled two or more series of botanical papers at each session. The efficient messenger system, however, readily enabled all to know the progress of all programs so that papers of special interest, though in different rooms, could readily be heard unless they actually conflicted in time.

An examination of the content of the botanical programs offered by the different sections of the affiliated societies shows a tendency towards greater variety than formerly. The strict categories are breaking down, along certain lines at least, and it often happens that a given paper may very properly be classified or presented in two or more sections. This may be due to broader interest or better training of the present workers, but primarily to the growing appreciation of the interdependence of the several fields of plant science.

In a still larger sense the boundaries between zoology and botany as a whole are becoming rather shadowy in many places, and the physiologists, geneticists and ecologists properly pass from one class of material to another and follow both sides with keener interest. These facts bespeak the need for large scientific meetings where members of the several sciences may hold programs in parallel series with greater profit to all concerned. Though emphasized elsewhere, it may be repeated here that modern buildings such as those at the Massachusetts Institute of Technology afford ideal conditions for holding such meetings as those recently held in Boston.

The invitation program of Section G was held on Wednesday afternoon as a joint session with the Botanical Society of America and the American Phytopathological Society. The program, which was attended by a large number of botanists, included the address of the re-

[1] Even at e the evidence of increasing T may be masked by the incipient solidification.

tiring vice-president, Mel. T. Cook, on "The original development of plant galls," and a symposium of four papers dealing with certain aspects of sterility in plants. In his address, Mr. Cook discussed the ontogeny and phylogeny of plant galls, their relations to the causal organisms and factors, together with practical considerations of their economic importance. In the symposium, Dr. A. B. Stout's paper, read by Professor R. A. Harper, discussed the cultural and experimental aspects of sterility from a physiologist's viewpoint. Professor Bradley M. Davis analyzed the bases of sterility, taking up both pollen and seed sterility, and calling attention to another type of sterility due to weak and inefficient seedlings. Cross and self sterility in their genetical bearings were taken up by Dr. E. M. East, who discussed the causes and control of pseudo-fertility, together with the mutual and reciprocal relations of self-sterile strains. Dr. M. J. Dorsey, in taking up the relations of sterility to horticulture, dealt with the status of sterility in cultivated plants, especially in relation to the environmental influences, and other problems related to the practical handling of cultivated plants.

During the autumn the Section Committee balloted by mail, and following their nomination, C. J. Chamberlain was elected vice-president for Section G, and R. A. Harper as member of the Section Committee.

On Thursday evening occurred the dinner for all botanists, following which was given the address of the retiring president of the Botanical Society of America, Dr. C. E. Allen. In his address Dr. Allen dealt with the potentialities of the plant cell as expressed in its structural and functional specializations. Other speakers on the program discussed the need of a tropical research laboratory, and the present status of *Botanical Abstracts*.

THE BOTANICAL SOCIETY OF AMERICA

President, Henry C. Cowles.

Secretary, Ivey F. Lewis, University of Virginia, University, Va.

(Report by I. F. Lewis)

The seventeenth annual meeting of the Botanical Society of America was held in affiliation with the American Association for the Advancement of Science at the Massachusetts Institute of Technology on December 27, 28 and 29.

Officers were elected as follows: *President,* B. M. Duggar; *vice-president,* J. R. Schramm; *secretary,* I. F. Lewis; *treasurer,* I. W. Bailey; *editors, American Journal of Botany,* William Crocker, R. A. Harper, Donald Reddick; *representative, division of biology and agriculture, National Research Council,* J. M. Coulter.

For the first time in the history of the Society "corresponding members" were elected, these being Hugo De Vries and F. O. Bower.

Formal approval was given to the project to establish in Washington a national arboretum and garden, and cooperation was promised the Botanical Society of Washington to bring this about.

The annual dinner for all botanists was held on Thursday evening. President H. C. Cowles presided. After short talks by Dr. A. S. Hitchcock, Dr. William Crocker, and Professor B. M. Davis, the retiring president, Dr. C. E. Allen, delivered the annual address on "The potentialities of a cell."

The Society met with the New England Botanical Society on Friday evening at the home of the American Academy of Arts and Sciences.

General Section

(Report by John T. Buchholz)

In a brief discussion, A. J. Eames, of Cornell University, called attention to the remarkable uniformity in vascular anatomy of the nodes of plant stems, suggesting how the facts of plant anatomy may be used in solving the puzzles of the relationships of plant orders and families. Carpels have three bundle traces without known exception, while stamens have only one bundle trace, this being derived from three. Since petals have only one trace a majority of them are stamens, while sepals are bracts or leaves in origin. The fact that gymnosperms have only one or two traces, never three, suggests that angiosperms are an isolated group and were not derived from known gymnosperms.

As an illustration of the use which may be made of vascular anatomy in solving problems of relationships, Dr. Eames presented a paper by Miss Mary Jones Fisher, in which the morphology of the flower of willows was investigated. This work in vascular anatomy shows that the floral parts of willows have suffered a

reduction, having been derived from a more highly specialized insect pollinated flower. They are therefore specialized groups rather than primitive plants, as looked upon at present by taxonomists.

Miss Alma G. Stockey, of Mt. Holyoke College, announced the discovery of the prothallium of *Lycopodium obscurum*, and exhibited living specimens of these gametophytes with young sporelings.

The structure and development of the polycladous form of *Sphærocarpus Donellii* was described by Alfred M. Wolfson, of the University of Wisconsin. This liverwort is also being investigated by C. E. Allen and his coworkers for the heredity of this character, this phase of the work having been reported by Dr. Allen before the Joint Genetics Section.

E. C. Jeffrey, of Harvard University, presented some new evidence that the crystals of Ginkgo are extracellular. His statement that the protoplast of these crystals together with its nucleus is entirely within the crystal brought forth a sharp discussion in which skepticism was expressed on the question of whether these observations were correctly interpreted, while Dr. Jeffrey indicated with no hesitation that he accepted the challenge to prove this point.

P. C. Mangelsdorf, of the Bussey Institution, described the nature of a number of endosperm anomalies in maize, some of them involving almost complete absence of endosperm.

That color inheritance in maize endosperm is an exceedingly complex problem was indicated by R. A. Harper, of Columbia University, who exhibited color plates showing a wide range of colors produced in the F_1 generation when certain strains are crossed, though the parent strains had been inbred for many generations. It has been generally accepted that all F_1 hybrids between highly inbred strains are similar.

Michael Levine, of New York City, who has been studying plant gall tissue in comparison with animal cancers, pointed out some important differences in these neoplasms. He explained that in animal cancers many cells go into division simultaneously, while in plants these cell divisions are uneven.

J. D. Hale reported that true bars of Sanio are found only in the secondary wood and are of diagnostic importance in relation to the groups in which they occur. In another paper, Mr. Hale interpreted the trabeculæ of Sanio as arising through fungal infection of the cambium and that they are associated in a radial series of locally depressed annual rings. J. D. Hale and M. J. Brophy reported that the strength of timbers varies with the rate of growth and is correlated with definite morphological characters.

R. H. Wetmore in tracing the evolution of lenticels showed that whereas in primitive forms they were related to appendages in higher type they are correlated with the rays. A. E. Longley in studying pollen development found but four out of thirty-seven forms of *Rubus* with normal pollen production and an even higher degree of irregularity in *Cratægus*, suggestive that most of these forms are of hybrid origin.

A study of traumatic tissue by A. E. Longley strengthens the hypothesis that the pines stand in a primitive position in the Abietineæ, rather than as reduced forms.

Physiological Section

Chairman, William Crocker.

Secretary-treasurer, R. B. Harvey; University of Minnesota, University Farm, St. Paul, Minn.

(*Report by R. B. Harvey*)

The program of the Plant Physiologists consisted of three general sessions and two symposia. The 29 papers presented in the general sessions displayed greater interest in plant physiological problems than has been shown at any previous meeting. Papers on salt absorption and general nutrition occupied the major part of the Wednesday morning and the Friday afternoon sessions. Papers relating to permeability and oxidative changes were given on Friday morning. Among the papers given at this session there was presented a method for determining the oxygen-supplying power of the soil, a factor which is of much importance and which has been difficult to determine. At the symposium on "Mosaic diseases," held in joint session with the American Phytopathological Society, the contributions on this subject mark an epoch in the study of these important diseases. The symposium with Section C (Chemistry) held Thursday afternoon, on photosynthesis and photochemical reactions, attracted much attention; it was a very thorough and complete presentation of the problems related

to photosynthesis. The discussion covered the general nature of photochemical reactions in plants, in particular, and the physiology and chemistry of the utilization of the assimiliate. The program was of great interest throughout, although unusually long.

The following officers were elected: *Chairman,* Professor Lewis Knudson; *vice-chairman, Pacific Section,* E. T. Bartholomew, R. B. Harvey; *secretary-treasurer,* R. B. Harvey.

Mycological Section

Chairman, C. L. Shear.

(*Report by C. L. Shear*)

Two sessions of the Mycological Section of the Botanical Society of America were held, at which 19 papers were presented. About 50 members were in attendance.

R. H. Colley and Minnie W. Taylor discussed peridermia of five-needled pines, pointing out that there are two other species besides the one belonging to *Cronartium ribicola* which are very closely related to it but distinguishable by certain spore characters. Dr. Colley also discussed methods in spore measurement, pointing out the necessity for standardizing our methods of measuring spores so that the results of different workers may be comparable.

H. S. Jackson and E. B. Mains discussed *Aecidium Myosotidis* Burr., a rather rare species which is connected with telia on grasses. Dr. Jackson also gave observations on the Micro-Puccinias, pointing out the remarkable similarity between the telia-spores of certain short-cycled forms and long-cycled forms on the same host.

B. O. Dodge discussed the morphology and host relations of *Pucciniastrum americanum,* a rust of red raspberries which was rather severe in a plantation near Washington the past season. Dr. Dodge also discussed the systematic infection of species of Rubus with the orange rusts, showing how and when infection occurs, and that systematic infection can be easily demonstrated by microscopic examination of sections of roots or stems.

F. D. Fromme gave a description with illustrations of an undescribed species of rust on the cow-pea. This is closely related to, and has been confused with other common rusts on closely related plants.

E. M. Gilbert read a paper on cytological studies of some uredineæ, discussing the nuclear behavior in short-cycled puccinas on Circaæ and from Cryptotænia.

S. A. Wingard read a paper on nuclear phenomena in ascospore formation of a parasitic yeast, tracing the development of the ascospores in a remarkable fungus which has been found parasitic on lima beans.

In a paper by Leva B. Walker, giving observations on the development of *Endogone malleola,* the morphology of this rather rare fungus was described as it appears in pure culture and in nature.

Cultural studies of *Armillaria mellea* Fr. and *Clitocybe monodelpha* Morg. were presented by Miss C. Audrey Richards. The close similarity in appearance of pure cultures of these two fungi was pointed out, and the slight difference in the Armillaria taken from different hosts were shown.

J. J. Taubenhaus and D. T. Killough presented recent advances in our knowledge of Texas root rot of cotton, *Ozonium omnivorum,* describing successful inoculation experiments not previously reported and giving data relating to the mode of over-wintering of the fungus in the field.

The physiology of perithecia formation in *Valsa leucostoma* was given by Leon H. Leonian. It was shown that the formation of pycnia and perithecia could be controlled by variations in the nutrient media and by transfers to media of different composition.

Michael Levine gave results of further study on the behavior of crown gall on the rubber tree, *Ficus elastica,* showing the effect upon plants in which the tips had been killed by the gall organisms.

C. L. Shear in a paper on Phoma—as a sample of mycological nomenclature and classification—pointed out the great confusion which now exists in the application of this name and the wide departure from its original usage by its author, Fries, as a monotype genus, showing the need of fixing generic names by the application of the type method.

Margaret B. Church and Charles Thom discussed the relation of commensalism in common molds to taxonomy, pointing out the confusion which sometimes arises from the fact that certain molds frequently grow in such close association in culture that they are easily confused.

A preliminary note on the peculiar marine phycomycete, Coenomyces, by I. F. Lewis and W. H. Weston, Jr., was presented by Dr. Weston. This peculiar and interesting fungus has not heretofore been reported except from Russia.

David H. Linder reported on a Rhizopogon new to the eastern United States. The fungus appears to be a species identical with one from California.

H. M. Fitzpatrick gave an outline of a monograph of the genus Nitschkia and related genera, indicating his proposed method of treatment of the group.

Dr. W. H. Weston, Jr., of Harvard University, was elected chairman of the section.

Systematic Section

Chairman, M. L. Fernald.

Secretary, Alfred Gundersen, Brooklyn Botanic Garden, Brooklyn, N. Y.

(*Report by Alfred Gundersen*)

Two sessions were held and fourteen papers presented. On Thursday F. W. Pennell presented evidences of parallel lines of evolution in *Afzelia.* M. L. Fernald, speaking of the flora of eastern Canada, concluded that no fundamentally distinct species had evolved there since the glacial periods. Miss A. Brackett compared seeds and floral characters in *Hypoxis.* W. W. Eggleston presented researches on *Zygadenus.* N. C. Fassett spoke on estuary floras. C. O. Rosendahl described two new species of *Sullivantia,* his paper being read by Mr. Butters.

At the session on Friday, P. A. Rydberg proposed dividing the *Galegeæ* into eleven subtribes instead of five. A. S. Hitchcock spoke on the type-basis code, a modified form of the American code. Alfred Gundersen presented a diagram of orders of dicotyledons. A. J. Eames and P. A. Rydberg discussed the nature of epigynous flowers. I. M. Johnston spoke on the fauna and flora of southern Lower California, concluding that the fauna has a northern and the flora a Mexican origin. B. L. Robinson urged the need of greater monographic activity in America, as contrasted with regional investigations.

Following the reading of papers, John H. Schaffner, of Ohio State University, was elected chairman for 1923, and Alfred Gundersen was reelected secretary.

THE AMERICAN PHYTOPATHOLOGICAL SOCIETY

President, E. C. Stakman.

Secretary, G. R. Lyman, U. S. Department of Agriculture, Washington, D. C.

(*Report by F. D. Kern*)

The program for the Boston meeting of the American Phytopathological Society included eighty-nine papers. In addition two sessions were in the nature of conferences at which formal papers were not presented. Most of the papers were presented, but a few authors, as usual, sent titles without any provision for their presentation. The custom of publishing the abstracts so that each member may have a copy at the meeting was continued this year. There was but a single session at which miscellaneous papers were read. Special sessions were as follows: Mosaic diseases, diseases of fruits and trees, diseases of potatoes and truck crops, diseases of cereals, a conference on potato inspection methods, a round-table discussion on extension methods as applied to plant pathology, a joint session with the American Association of Economic Entomologists on plant quarantines, and a joint session with Section G and the Botanical Society of America in which the address of the retiring vice-president, Mel. T. Cook, of Section G, was on a pathological topic, "The origin and structure of plant galls."

Without doubt the most important section of the program was that dealing with mosaic diseases of plants, a joint session with the Physiological Section of the Botanical Society. The most striking contribution, and one that marks a great step forward in the science of phytopathology, was a demonstration of the occurrence of protozoans in plants affected with mosaic and related diseases. In the mosaic of tomato, bean and clover, and also in potato leaf roll, Ray Nelson demonstrated in longitudinal sections the presence of biflagellates and trypanosomes. Kunkel and McKinney, Eckerson and Webb made contributions concerning the presence of intracellular bodies in mosaic tissues of *Hippeastrum* and in rosette of wheat. The distribution of both the flagellates and intracellular bodies in the host tissues and their frequent application to the host